

Theory Working Group Summary

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Focus of the Working Group

What are the most interesting questions about whose answers we can learn a lot from near-term future experiments (i.e. before LBN* goes online)?

What are the roles of the theorists in the pursuit of answering these fundamental questions?

Topics Covered

- Discussion: 3-nu oscillation paradigm [Patrick Huber]
- Short baseline anomalies [Boris Kayser]
- Supernova neutrinos [Alex Friedland]
- Neutrino telescopes: Physics and astrophysics [Irina Mocioiu]
- Neutrino masses and BSM physics [Lisa Everett]
- Discussion: Neutrino interactions [Richard Hill]
- Discussion: Neutrinoless double beta decay [André de Gouvêa]

Dirac vs Majorana Nature

- Improved searches for neutrinoless double beta decay is the best bet to address this fundamental question.
- Inverted neutrino spectrum may be within reach in such experiments.

Direct Neutrino Mass Measurement

- Determining the absolute neutrino mass scale in Tritium beta decay experiments would provide deep insight into the origin of neutrino masses.

Mass Hierarchy and Possible Sensitivity to CPV

- Any progress towards measuring the neutrino mass hierarchy before LBN* would be highly desirable.
- In particular, knowing the hierarchy is crucial for the possibility of obtaining a hint for the value of the leptonic CP violating phase prior to ELBNF.

Testing 3nu Oscillation Paradigm

- Consistency checks of the three neutrino oscillation paradigm: This requires a variety experimental information including:
 - Improved knowledge of neutrino oscillation parameters from solar, atmospheric, and reactor neutrino experiments.
 - Essential information on neutrino interaction rates from experiments.

Neutrino Interactions

- Neutrino-nucleus interactions: Knowing the interaction rates is crucial for addressing many of the important questions in neutrino physics, including the consistency checks of the three neutrino oscillation paradigm.

Testing 3nu Oscillation Paradigm

- **Short baseline anomalies:** Unambiguous resolution in terms of oscillations would require seeing L/E dependence in new/upgraded experiments.
- **Existence of sterile neutrinos:** Discovery of new sterile states in neutrino oscillation experiments attempting to resolve short baseline anomalies will be foundational.
- **Nonstandard neutrino interactions:** If discovered, these effects would invalidate the three neutrino oscillation paradigm, and hint at new physics beyond neutrino masses.

Neutrinos in Astrophysics and Cosmology

- **Supernova neutrinos:** Nearby supernova explosions can show neutrino signals any time, watching out for them can pay hefty dividends.
- **High energy astrophysical neutrinos:** IceCube and its upgrade will tell us more about the origin of very high energy (PeV scale) astrophysical neutrinos. Energy spectrum, directional information, and flavor composition of these events can help us understand the astrophysical sources as well as neutrino properties.
- **Neutrinos in cosmology:** Although indirect, neutrino masses inferred from cosmology would provide complementary information, and at the same time also test standard cosmological models.

Nucleon Decay

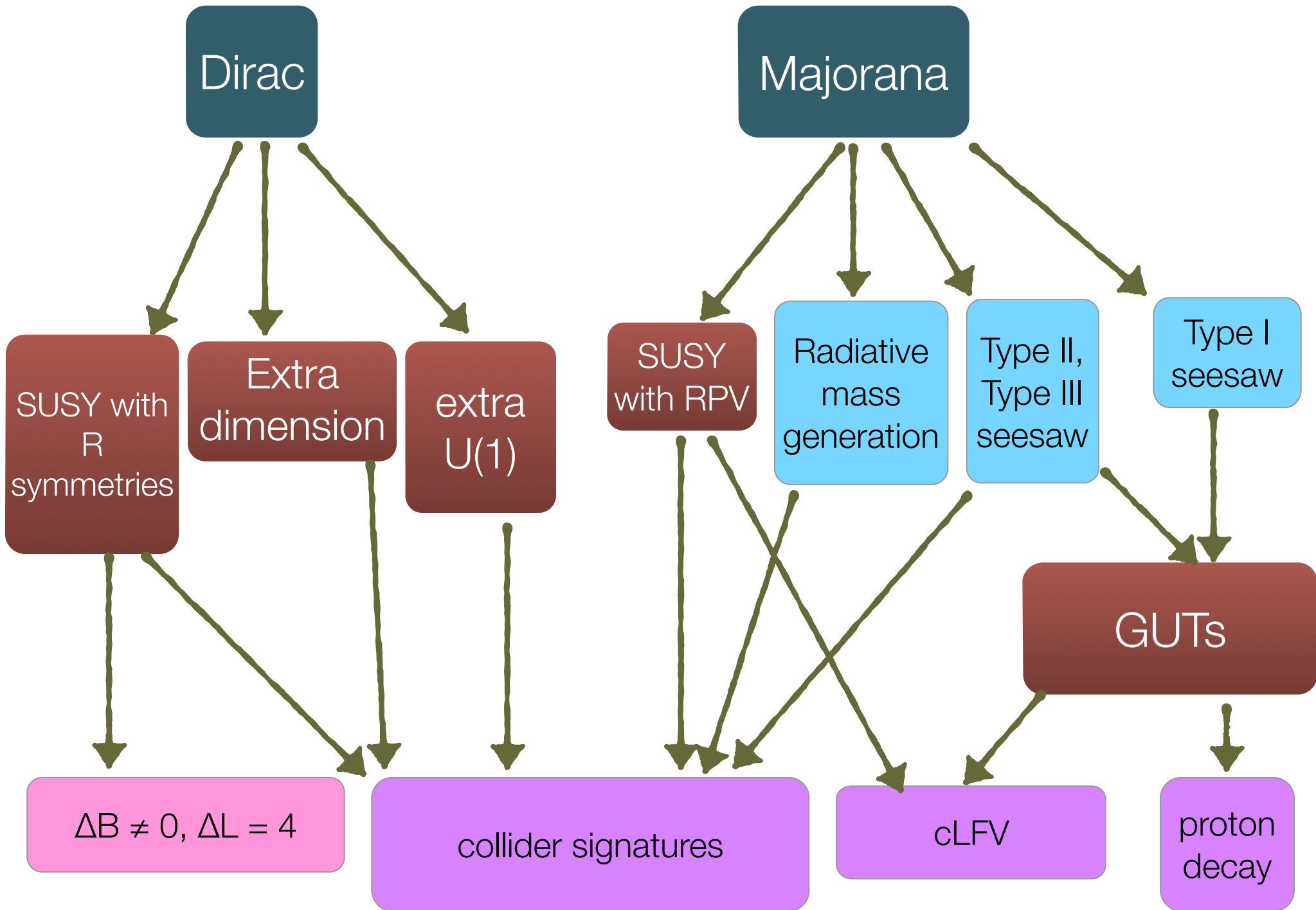
- Ongoing large underground detectors (SuperKamiokande) which are sensitive to neutrino oscillation physics continue to be also sensitive to nucleon decay.
- Discovery of nucleon decay would be monumental.

Exotic Neutrino Properties

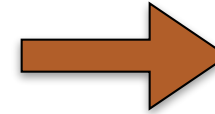
- Information on neutrino properties such as its magnetic moment, decay lifetime, possible violations of Lorentz invariance and/or CPT invariance, and possible existence of neutrino-dark matter interactions would be valuable.
- Even if not found, neutrinos can provide some of the best tests of these fundamental symmetries.

Neutrino Models and BSM Physics

- What can neutrino experiments teach us about the underlying symmetries of the theory that generates neutrino masses?

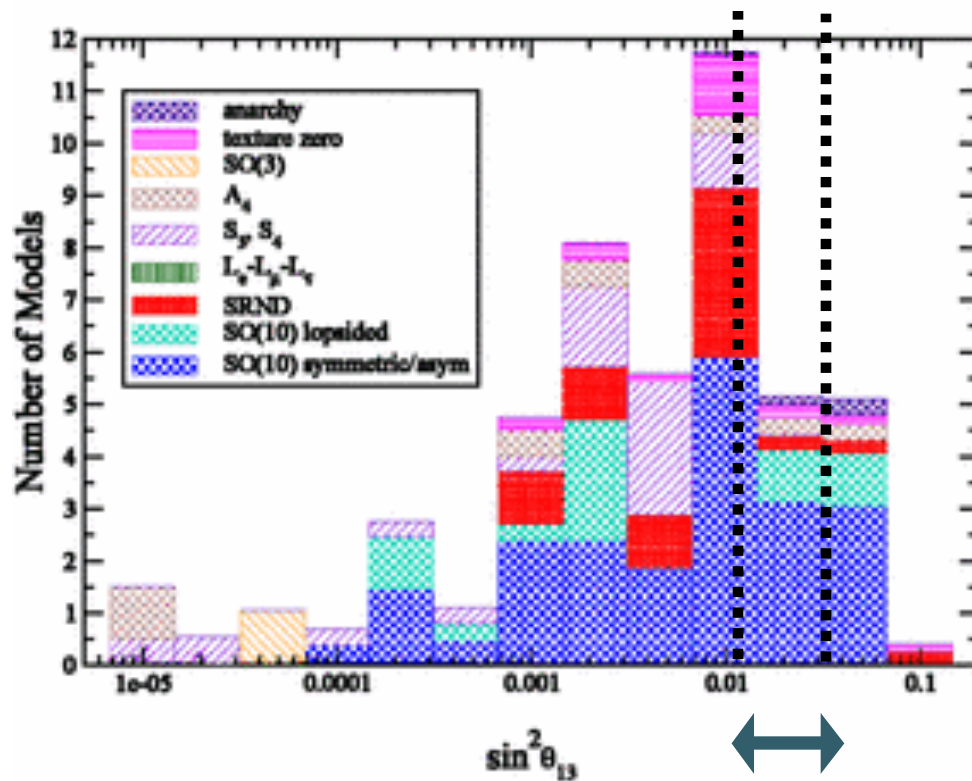


Mixing Parameters and Mass ordering

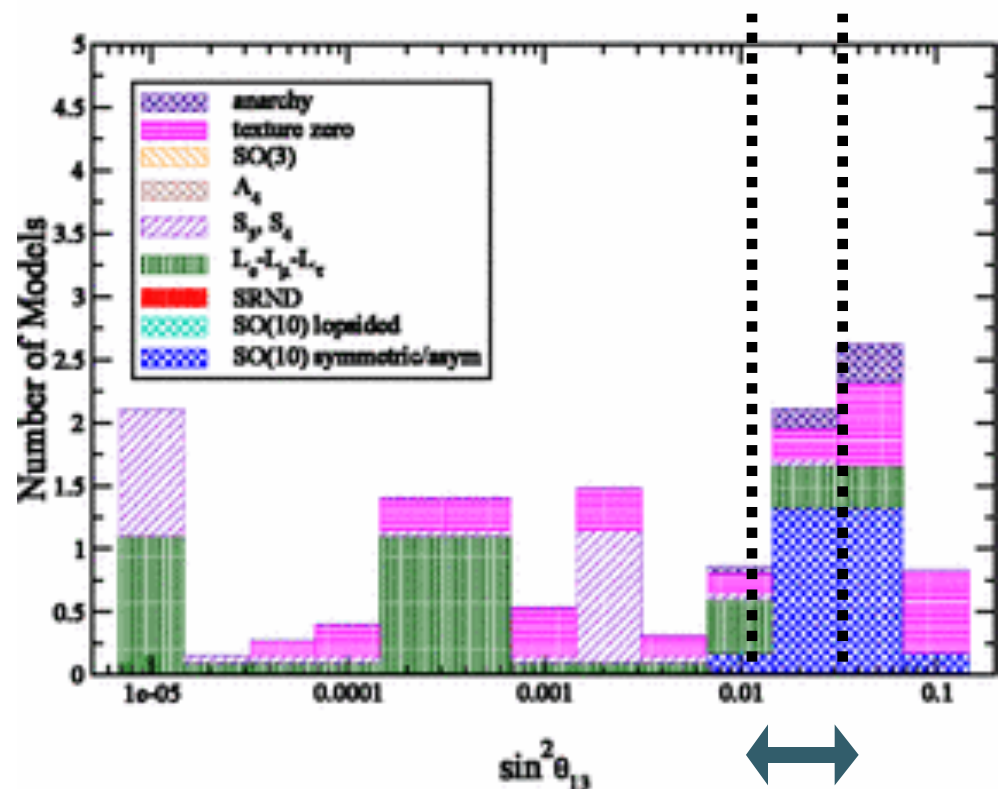


underlying symmetries

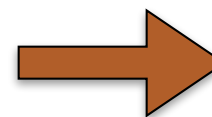
Normal Hierarchy



Inverted Hierarchy



Mixing Parameters and Mass ordering



underlying symmetries

symmetries \Rightarrow experimentally observable correlations

BM

$$\theta_c + \theta_{\text{sol}} \cong 45^\circ$$

Raidal, '04; Smirnov, Minakata, '04

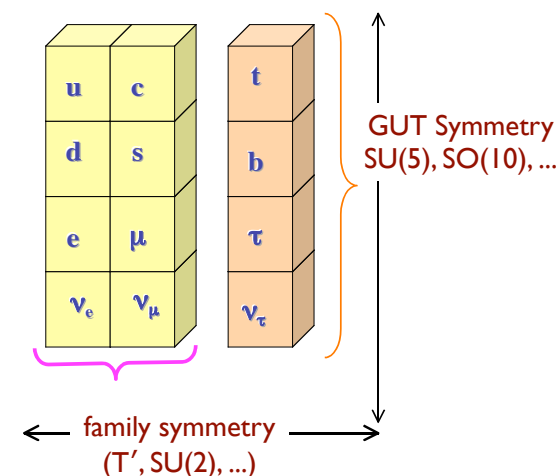
$$\theta_{23}^q + \theta_{\text{atm}} \cong 45^\circ$$

TBM

$$\tan^2 \theta_{\text{sol}} \cong 1/2 + (\theta_c / 2) \cos \delta_e$$

$$\theta_{13}^e \cong \theta_c / 3\sqrt{2}$$

Ferrandis, Pakvasa; King; Dutta, Mimura; M.-C.C., Mahanthappa



New Theory Insights towards Origins of Flavor and CP Violation

e.g. discrete family symmetries

\Rightarrow group theoretical origin of CP violation

M.-C. C., K.T. Mahanthappa (2009); M.-C. C., M. Fallbacher, K.T. Mahanthappa, M. Ratz, A. Trautner (2014)

Roles of Theorists

- **Neutrino interactions:**
 - important for getting the correct experimental results
 - bridging the theory predictions with experimental results [e.g. $0\nu\beta\beta$, proton decay]
- **Phenomenologists:**
 - state of the art tools for global fit
 - framework to discuss general setup [e.g. NSI, sterile nu spectra]
- **Model builders:**
 - motivate experimental searches that can lead to fundamental discovery, e.g. GUTs \rightarrow giant detector \rightarrow discovery of neutrino oscillation
 - interpret (unexpected) experimental results with new physics

This is an area where a small investment can have a HUGE return.

To have a healthy and sustainable field, strong support for neutrino theory from the entire community is indispensable.